The Penetron Conjecture:
Hypothetical Superluminal Non-Geodesic Particles and the Penetrability of Black Hole Event Horizons

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Abstract

We introduce the *Penetron conjecture*: the hypothesis that a class of hypothetical particles exists – called *Penetrons* – which travel at speeds $v > c$, do not follow the geodesics of spacetime, and are therefore capable of penetrating and traversing the event horizon of a black hole. The conjecture arises from a physical argument about the extreme density of black hole interiors: compressed matter at supernuclear densities leaves no void through which electromagnetic radiation can propagate freely, and any particle that could penetrate such a medium must be rigid in its trajectory and superluminal in its speed. We formalize the three defining properties of Penetrons, discuss their relationship to the black hole information paradox, and compare them to existing hypothetical constructs (tachyons, ageodesic particles). The conjecture is explicitly speculative and is presented as an open problem for theoretical physics.

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1 Motivation

1.1 The density argument

The interior of a black hole, under the gravitational collapse of stellar or galactic matter, accumulates compressed material over billions of years. The resulting density at and near the central singularity exceeds all known densities in the observable universe – nuclear density ($\sim 10^{17}$ kg/m^3) is itself already far below what the equations of general relativity predict near $r = 0$.

A useful physical analogy: consider used motor oil that has accumulated on the ground over time. Initially fluid, it condenses, thickens, and eventually hardens into a dense, nearly impenetrable substance. Nothing penetrates it easily. The black hole interior is the cosmic equivalent – matter compressed link by link, over cosmological timescales, into a state of extreme rigidity.

In such a medium, the void through which electromagnetic radiation propagates freely does not exist. Light, which achieves speed c in vacuum and slows in denser media (water: $v \approx 0.75c$; glass: $v \approx 0.67c$), would find no available path in the compressed interior. The refractive index $n \to \infty$ effectively, and $v_{\text{light}} \to 0$.

This is consistent with the geometric description: at the Schwarzschild radius $r_s = 2GM/c^2$, the escape velocity equals c and all outgoing null geodesics are bent back inward. The interior is sealed.

1.2 The penetration question

This raises a natural question: if ordinary particles and radiation cannot exit a black hole, could a hypothetical particle with fundamentally different properties – superluminal speed and non-geodesic trajectory – do so?

We call such hypothetical particles *Penetrons* and formalize their defining properties in the following section.

2 The Penetron: Three Defining Properties

Definition 1 (Penetron). *[Speculative/Open] A* Penetron *is a hypothetical particle characterized by the following three properties:*

(i) ***Superluminal velocity:*** *$v > c$ at all times.*

(ii) ***Non-geodesic trajectory:*** *the Penetron does not satisfy the geodesic equation*

$$\frac{d^2x^\mu}{d\tau^2} + \Gamma^\mu_{\nu\rho}\frac{dx^\nu}{d\tau}\frac{dx^\rho}{d\tau} = 0. \tag{1}$$

That is, the Penetron trajectory satisfies

$$\frac{d^2x^\mu}{d\tau^2} + \Gamma^\mu_{\nu\rho}\frac{dx^\nu}{d\tau}\frac{dx^\rho}{d\tau} \neq 0. \tag{2}$$

(iii) ***Horizon penetrability:*** *a Penetron can cross the event horizon $r = r_s$ in both the inward and outward directions.*

Remark 1. *Properties (i) and (ii) are logically independent. A tachyon (hypothetical superluminal particle in special relativity) satisfies (i) but still follows geodesics. The Penetron requires both: superluminal speed alone is insufficient if the particle still curves with spacetime geometry and is trapped inside r_s.*

3 Physical Interpretation

3.1 Why non-geodesic?

In general relativity, all particles – massive and massless – follow geodesics of the spacetime metric. Geodesics are the "straightest possible paths" in curved spacetime. Near a black hole, even radially outward geodesics are bent back inward for $r < r_s$.

A non-geodesic particle "cuts through" the geometry rather than following it. In the analogy of the arrow: light bends around a gravitational obstacle; a Penetron, like an arrow shot with extreme precision and speed, does not deflect.

Formally, the deviation from geodesic motion can be written as:

$$a^{\mu}_{\text{Penetron}} = \frac{d^2x^{\mu}}{d\tau^2} + \Gamma^{\mu}_{\nu\rho}\frac{dx^{\nu}}{d\tau}\frac{dx^{\rho}}{d\tau} = f^{\mu} \neq 0, \tag{3}$$

where f^{μ} is a hypothetical "rigidity force" that maintains the straight trajectory against spacetime curvature. The nature and origin of f^{μ} is an open problem.

3.2 Why superluminal?

The event horizon condition in Schwarzschild geometry states that a particle at $r = r_s$ requires escape velocity $v_{\text{esc}} = c$ to exit. For $r < r_s$, the required escape velocity exceeds c. Therefore:

Proposition 1. *[Follows from Schwarzschild geometry] Any particle that exits a black hole interior from $r < r_s$ must satisfy $v > c$ at the moment of crossing the horizon.*

This is a necessary condition. Whether it is sufficient – i.e., whether $v > c$ alone enables escape – depends on the trajectory: a superluminal particle following a geodesic is still trapped inside r_s. Both properties (i) and (ii) are required simultaneously.

3.3 Connection to the information paradox

The black hole information paradox (Hawking, 1976) asks: when a black hole evaporates via Hawking radiation, is the information encoded in the matter that fell in preserved or destroyed?

Current proposals (Page, Penington, Almheiri et al.) suggest information is encoded in Hawking radiation through subtle quantum correlations. All such proposals assume no classical channel exists between the interior and exterior.

If Penetrons exist, a new channel would be available: information could be carried outward by Penetrons crossing the horizon. This would resolve the paradox in a fundamentally different way – not through quantum entanglement of radiation, but through a new class of information-carrying particles.

Conjecture 1 (Penetron Conjecture). *[Open] There exists a class of particles – Penetrons – satisfying Definition 1. If such particles exist, they constitute a classical information channel between the interior and exterior of a black hole, providing a novel resolution mechanism for the black hole information paradox.*

4 Comparison with Existing Constructs

Particle	$v > c$	**Non-geodesic**	**Horizon penetrability**
Photon	No	No	No
Tachyon (SR)	Yes	No	No
Graviton	No	No	No
Penetron	**Yes**	**Yes**	**Yes**

Table 1: Comparison of the Penetron with existing hypothetical and known particles.

The Penetron is distinct from all known hypothetical constructs. The tachyon, proposed in special relativity, travels faster than light but still follows the causal structure of flat spacetime and does not resolve the horizon problem in a curved spacetime context. The Penetron requires both properties simultaneously.

5 Open Problems

The following questions are left open:

1. **Origin of the rigidity force** f^μ: what physical mechanism prevents a Penetron from following the geodesic? Is it a new fundamental interaction, or an emergent property of quantum gravity?

2. **Mass and spin**: what are the quantum numbers of a Penetron? A superluminal particle in special relativity has imaginary rest mass ($m^2 < 0$). Does this extend to the curved spacetime context?

3. **Detectability**: if Penetrons exit black holes, what observational signature would they leave? Could they be detected by existing or future instruments (LIGO, Event Horizon Telescope, future gravitational wave detectors)?

4. **Consistency with causality**: superluminal particles generically threaten causality (closed timelike curves). Under what conditions, if any, can Penetrons exist without violating causality?

5. **Quantum extension**: in a full quantum gravity theory, do Penetron-like excitations appear naturally? Are they related to the island formula or replica wormhole constructions in recent holographic approaches to the information paradox?

6 Discussion and Scope

This paper is explicitly speculative. We do not claim that Penetrons exist. We claim that the question of their existence is physically well-posed, that their defining properties are formally consistent, and that if they exist, they have profound implications for black hole physics and the information paradox.

The conjecture arises from a physical intuition – the density argument of Section 1 – combined with a formal observation about the necessity of non-geodesic superluminal motion for horizon crossing. We present it as an open problem for theoretical physics.

The name *Penetron* reflects the defining property: a particle that penetrates what nothing else can.

7 Addendum: Penetrons as the Mechanism of Hawking Radiation

Added March 13, 2026, as a natural extension of the conjecture following the initial deposit (DOI: 10.5281/zenodo.18990284).

Hawking radiation (Hawking, 1974) predicts that black holes emit thermal radiation and slowly lose mass. The standard description invokes virtual particle pairs created near the event horizon: one particle falls inward, the other escapes outward. The black hole loses mass equivalent to the escaping particle's energy.

This description raises an immediate question: *what carries the energy and information outward across the horizon?* In standard quantum field theory, the answer involves subtle quantum correlations – entanglement between infalling and outgoing modes. No classical particle crosses the horizon outward.

We propose a complementary conjecture.

Conjecture 2 (Penetron–Hawking Mechanism)**.** *[Speculative/Open] Penetrons are the physical carriers of Hawking radiation. Specifically:*

(i) Penetron–anti-Penetron pairs are created spontaneously near the event horizon, analogously to the Schwinger effect in strong fields.

(ii) The anti-Penetron crosses the horizon inward, carrying negative energy consistent with the black hole losing mass.

(iii) The Penetron crosses the horizon outward, carrying energy and information to the exterior.

(iv) What is observed as Hawking radiation is the energy flux of outgoing Penetrons, thermalized by interactions with the near-horizon geometry.

7.1 Why photons cannot play this role

Standard photons follow null geodesics. Any particle following a geodesic inside $r < r_s$ cannot exit – all outgoing null geodesics are bent back inward. Photons are therefore structurally incapable of carrying information outward across the horizon by classical propagation.

Penetrons satisfy $v > c$ and follow non-geodesic trajectories. They are not subject to the geometric trapping that confines photons. This makes them the only hypothetical classical carriers capable of crossing the horizon outward.

7.2 Energy transport and consistency condition

The total energy flux of Hawking radiation for a black hole of mass M at Hawking temperature $T_H = \hbar c^3/(8\pi G M k_B)$ satisfies:

$$\frac{dM}{dt} = -\frac{\hbar c^4}{15360\pi G^2 M^2} \tag{4}$$

In the Penetron–Hawking mechanism, this flux is carried by outgoing Penetrons. The two descriptions – standard quantum field theory and the Penetron mechanism – must agree on the total energy flux. This provides a consistency condition constraining the Penetron coupling to the near-horizon geometry.

7.3 Observational signatures

If Penetrons carry Hawking radiation, distinctive signatures may include:

1. Spectral deviations from a perfect blackbody at high energies, where non-geodesic Penetron dynamics become significant.
2. Classical encoding of information in Penetron degrees of freedom rather than quantum entanglement – implying in principle a complete classical record of the black hole's history.
3. Suppression of Penetron production near extremal black holes (where $T_H \to 0$), providing a prediction distinguishing this mechanism from standard Hawking radiation.

Hawking radiation itself has never been directly detected – it is too faint for current instruments for any known astrophysical black hole. The Penetron–Hawking mechanism is therefore doubly speculative: a proposed mechanism for a phenomenon not yet experimentally confirmed. We present it as an open problem at the intersection of quantum gravity, black hole thermodynamics, and hypothetical superluminal particle physics.

Addendum v3 (March 13, 2026): The Conversion Mechanism

Horizon velocity and the conversion of ordinary matter

This addendum proposes a third mechanism by which Penetrons may arise at black hole horizons — distinct from the pair-creation mechanism of Addendum v2.

At the event horizon $r = r_s$, the free-fall velocity of infalling matter reaches c. This is not a coincidence but the defining property of the horizon: it is the surface at which escape velocity equals c, and consequently at which infalling velocity also reaches c. In the frame of an infalling observer, the local spacetime geometry becomes extreme — tidal forces diverge for a Schwarzschild singularity, and all null geodesics converge inward.

The conversion conjecture: We conjecture that the extreme acceleration experienced by matter approaching $r = r_s$ constitutes a conversion mechanism. Ordinary matter — including photons, which the black hole treats identically to massive particles at the horizon — undergoes a phase transition induced by the infinite acceleration. The product of this conversion is Penetrons.

Formally, let a_{local} be the proper acceleration experienced by a particle held stationary near the horizon at radius $r = r_s + \epsilon$:

$$a_{\text{local}} = \frac{c^4}{4GM} \cdot \frac{1}{\epsilon} \to \infty \quad \text{as} \quad \epsilon \to 0 \tag{5}$$

This diverging acceleration, in the Unruh effect, corresponds to a diverging local temperature $T_{\text{Unruh}} = \hbar a_{\text{local}}/2\pi c k_B$. We conjecture that at the critical acceleration where T_{Unruh} exceeds a conversion threshold T_{conv}, ordinary matter undergoes a transition to Penetron states:

$$\boxed{T_{\text{Unruh}}(r) \geq T_{\text{conv}} \implies \text{matter} \to \text{Penetron}} \tag{6}$$

Light as matter at the horizon

The black hole does not distinguish between photons and massive particles at the horizon. Both follow geodesics that terminate at r_s. Both are subject to the same extreme acceleration in the near-horizon geometry.

In this picture, infalling light is converted by the same mechanism as infalling matter. The photon arrives at the near-horizon zone, experiences diverging acceleration, and undergoes the conversion transition. The outgoing Penetron carries the energy and information of the original photon.

The Penetron's resistance to conversion

Ordinary matter converts because it follows geodesics — it has no resistance to the curvature that drives the conversion. The Penetron, being non-geodesic by definition, possesses a trajectory rigidity that ordinary matter lacks.

A Penetron incident on a black hole horizon is not subject to the conversion mechanism. It may be deflected in direction by the local curvature, but it cannot be converted into another particle species — it already is a Penetron. It traverses the horizon without transformation.

This asymmetry — ordinary matter converts into Penetrons at the horizon, while Penetrons themselves are immune to conversion — provides a natural arrow of information flow: outward, via the Penetron channel.

Spaghettification as the preparatory phase

Remark 2 (Spaghettification and conversion)**.** *[Open — v3] The phenomenon known as spaghettification — the tidal stretching of infalling matter in the direction radial to the black hole — is, in this framework, the observable precursor of the conversion mechanism. Tidal forces stretch matter along the radial direction and compress it laterally as it approaches r_s. This is a purely geodesic, purely gravitational process visible from outside.*

We conjecture that spaghettification is the preparatory phase of conversion: it stretches matter to the point where the local Unruh temperature T_{Unruh} reaches the conversion threshold T_{conv}. At this threshold, the spaghettified matter does not continue to stretch indefinitely — it undergoes the phase transition into Penetrons.

The chain is therefore:

$$\textit{infalling matter} \xrightarrow{\textit{tidal forces}} \textit{spaghettification} \xrightarrow{T_{\text{Unruh}} \geq T_{\text{conv}}} \textit{Penetrons} \xrightarrow{\textit{outward}} \textit{Hawking radiation} \tag{7}$$

Spaghettification is what observers outside see. Conversion is what happens at the threshold. Hawking radiation is what emerges.

Hawking radiation as conversion product

Conjecture 3 (Conversion Mechanism). *[Open — v3] The observed Hawking radiation is the energy flux of Penetrons produced by the conversion of infalling matter and photons in the near-horizon zone $r_s < r < r_s + \ell_P$, where ℓ_P is the Planck length. The conversion is triggered when the local Unruh temperature exceeds the conversion threshold T_{conv}. The Hawking temperature $T_H = \hbar c^3/8\pi GMk_B$ is the thermodynamic average of the Penetron emission produced by this conversion.*

Three mechanisms — a unified picture

The three versions of this paper now contain three complementary mechanisms for Penetron production at black hole horizons:

1. **v1 — Horizon penetrability:** Any particle exiting from $r < r_s$ must have $v > c$. Penetrons satisfy this by definition.
2. **v2 — Pair creation:** Penetron/anti-Penetron pairs are created near the horizon by the strong gravitational field, analogous to the Schwinger effect. The outgoing Penetron carries energy and information.
3. **v3 — Conversion:** Infalling matter and photons are converted into Penetrons by the diverging acceleration in the near-horizon zone. Hawking radiation is the energy flux of this conversion product.

These three mechanisms are not mutually exclusive. They may all operate simultaneously, each dominating in different regimes of black hole mass, spin, and accretion rate.

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